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CLIMATE OF THE WEST FRONT OF THE WASATCH PLATEAU IN CENTRAL UTAH[1]

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INTRODUCTION

Increasing demands for intensive use of the mountainous forest and range lands of the West make it imperative that fundamental plans for wild-land management be developed. Before these plans can be drafted satisfactorily a knowledge of the attendant climatic variations is necessary.

The amount of forage that mountain ranges furnish for range livestock is determined, to a large extent, by the climate, particularly in periods of drought. The success of revegetating already depleted mountain areas depends upon proper selection of species and methods to meet climatic conditions. Permanency and stability of valley farms, communities, and cities depend upon the yield of water from mountainous watersheds for irrigation, industrial, and culinary purposes. The uniformity and quantity of this yield are governed, to a large degree, by the climate and its seasonal and annual fluctuations.

A considerable amount of information concerning mountain climate is contained in many reports and publications dealing with special subjects. However, only limited information is available concerning the climate, especially its variation, of the various mountain vegetational zones. Among the chief writers on this subject are: Bates (2), Bates and Henry (3), Henry (4), Pearson (6), and Sampson (7).

This paper presents the important climatic data collected during the 20-year period from 1914 to 1934, within the four main vegetational zones of a valuable mountain region. The study was made in the immediate vicinity of the Great Basin branch of the Intermountain Forest and Range Experiment Station located on the Wasatch Plateau near Ephraim, Utah.

PHYSIOGRAPHIC FEATURES OF THE AREA

The Wasatch Plateau, the northernmost member of the high plateaus of Utah, and a part of the Colorado Plateau province, extends 75 miles from north to south and has a narrow summit, in most cases not more than 6 miles wide. The western front is a great monoclinal flexure, whose strata bend upward to the summit in a single sweep. The angle of sweep is diversified by minor irregularities which are not of such magnitude as to mask the general uplift.

The part of the plateau where the meteorological stations are located breaks off abruptly to the west. The stream in Ephraim Canyon rises at 10,300 feet elevation and drops to 5,900 feet at the edge of San Pitch Valley about 7 miles below, having an average gradient of approximately 630 feet to the mile. The rim of the plateau is notched by erosion so that it appears serrated and streams have trenched back toward the summit giving the plateau a divided appearance (figure 1).

VEGETATION OF THE AREA

From the valley floor to the summit of the plateau, wide variation in the flora is evident. Yet, within certain altitudinal limits the vegetation is strikingly similar and comparatively uniform and may be grouped into the following four vegetational zones: Piñon-juniper, oakbrush, aspen-fir, and spruce-fir.

The piñon-juniper zone, 5,200 to 6,500 feet in elevation, supports scattered stands of piñon (*Pinus edulis*) and juniper (*Juniperus scopulorum*) intermixed with patches of big sagebrush (*Artemisia tridentata*) with an understory of a limited number of grass and weed species.

The oakbrush zone, 6,500 to 8,000 feet in elevation, is characterized by compact stands of scrub oak (*Quercus gambelii*) interspersed with bigtooth maple (*Acer grandidentatum*) and serviceberry (*Amelanchier alnifolia*). Big sagebrush, true mountain mahogany, known locally as "birchleaf mahogany" (*Cercocarpus montanus*), and a moderate number of grass and weed species occupy the relatively small openings.

The aspen-fir zone, 7,500 to 9,000 feet, supports dense stands of aspen (*Populus tremuloides aurea*) interspersed with white fir (*Abies concolor*), Douglas fir (*Pseudotsuga taxifolia*), and Engelmann spruce (*Picea engelmanni*). These timber stands have an understory of snowberry (*Symphoricarpos areophilus*) and grasses and weeds. In the open parks, which are characteristic of this zone, perennial grasses, chiefly mountain brome (*Bromus carinatus*), and weeds are very abundant, sometimes forming a dense cover.

The spruce-fir zone, 9,000 to 11,000 feet above sea level, is chiefly open grasslands dotted with scattered stands of subalpine fir (*Abies lasiocarpa*) and Engelmann spruce. The grasses are chiefly slender wheatgrass (*Agropyron pauciflorum*) and Letterman needlegrass (*Stipa lettermani*). Yellowbrush (*Chrysothamnus lanceolatus*) and "sweet sage" (*Artemisia incompta*), together with weeds, sometimes form a complete cover.

[1] Data collected in cooperation with U. S. Weather Bureau.

[2] Credit is due to Dr. Arthur W. Sampson, University of California, who initiated the study; to C. L. Forsling, Director of Appalachian Forest Experiment Station, under whose direction the study was continued; to Prof. E. W. Nelson, Colorado State College, who collected part of the field data; to J. Cecil Alter, U. S. Weather Bureau, Salt Lake City, and to Dr. George Stewart, Intermountain Forest and Range Experiment Station, who contributed valuable criticism during the preparation of the manuscript.

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METEOROLOGICAL STATIONS UNDER STUDY

Four meteorological stations, located in the approximate centers of the four vegetational zones, ranging from the valley floor to near the summit of the plateau, were used in obtaining data in this study. In addition, three short-time record meteorological stations, two of which are located in the aspen-fir zone and the other in the piñon-juniper zone, were used for purposes of comparison (figures 7 and 8).

The location and the description of each meteorological station are listed in table 1.

Sampson (7), who selected the sites for the three upper meteorological stations in 1913, states:

> They are all in the same canyon, and the distance between the lowest and the highest stations in an air line is approximately 5 miles. Owing to the possibility of the results being influenced by the presence of trees and other objects in the vicinity of the physical instruments and growing plants, the stations are all located in the open, on slopes dipping slightly to south, and no vegetation is so close as to cast shadows on the instruments or potometers, except for a few minutes at sunrise and sunset.

TABLE 1.—*Location and description of meteorological stations established on the Wasatch Plateau in central Utah*

Meteorological station	Location	Date established	Slope	Exact elevation	Observer
				Feet	
Piñon-Juniper zone.	Manti, Utah	1892	Flat	5,575	U. S. W. B.
Do	Ephraim, Utah	1930	do	5,543	G. B. B. S. coop. U. S. W. B.
Oakbrush zone	Ephraim Canyon	1914	50° W	7,655	Do.
Aspen-fir zone	do	1914	Slight dip to S. & W.	8,850	Do.
Do	Mount Baldy (12-Mile Canyon).	1923		9,100	Manti N.F. coop. U. S. W. B.
Do	Mammoth (Fairview Canyon).	1920		8,700	Do.
Spruce-fir	Ephraim Canyon near summit.	1914	12° S	10,100	G. B. B. S. coop. U. S. W. B.

NATURE OF RECORDS

Temperature and precipitation records are year-long for the piñon-juniper zone for the 34-year period, 1901–34. Similar records for the oakbrush, aspen-fir, and spruce-fir zones are complete for the seasonal period, May 1 to November 1 since 1913 and 1914. In addition, year-long records of both temperature and precipitation for these three zones are available for the years 1914, 1915, 1916, 1919, and 1920, as well as year-long records of precipitation continuously since 1925.

Correlations made with available precipitation and temperature data of the three upper stations and the existing data at the piñon-juniper station are highly significant. In view of this relationship, normals for a 20-year period for the three higher stations were computed by comparisons with the data at the piñon-juniper station by the method described by Milham (5), making averages for all four stations comparable.

Soil temperature, soil moisture, relative humidity, and cloudiness records were kept for the oakbrush, aspen-fir, and spruce-fir zones and, in the main, are for the seasonal period, May 1 to November 1 since 1924.

CLIMATIC FACTORS

Precipitation.—Precipitation on the plateau area varies widely in amount and character between vegetational zones due to differences in elevation and topography. Records of the average annual precipitation for the four zones are: Piñon-juniper, 11.70 inches; oakbrush, 17.51 inches; aspen-fir, 29.48 inches; and spruce-fir, 28.01 inches (figure 2).

The amount of precipitation increases rapidly from the valley floor to an elevation of approximately 9,000 feet, above which a slight decrease takes place. Annual precipitation increases 2.8 inches, on an average, per thousand feet rise in elevation between the piñon-juniper and oakbrush zones, 10.0 inches between the oakbrush and aspen-fir zones, and decreases 1.2 inches per thousand feet rise in elevation between the aspen-fir and spruce-fir zones. Departures from this annual rate during the year are considerable, the minimum being 0.69 inch in June and the maximum being 8.25 inches in January. These findings agree favorably with former findings of Alter (1), Henry (4), and Pearson (6).

Seasonal precipitation (winter—Oct. 1 to May 1, and summer—May 1 to Oct. 1) shows similar increases. Records of winter precipitation in the four zones follow: Piñon-juniper 7.10 inches; oakbrush, 10.92 inches; aspen-fir, 21.02 inches; spruce-fir, 20.56 inches. Amounts of summer precipitation for the same zones are: Piñon-juniper, 4.60 inches; oakbrush, 6.59 inches; aspen-fir, 8.46 inches; spruce-fir, 7.45 inches. However, the average annual percentage of summer precipitation is greater in the lower zones, being 39 percent in the piñon-juniper, 38 percent in the oakbrush, 29 percent in the aspen-fir, and 27 percent in the spruce-fir zones.

Monthly precipitation fluctuates widely within and between zones. Precipitation is lightest during the month of June and heaviest during March in all zones. A secondary rainy season occurs in this area during July and August followed by a dry period during September. After September, monthly precipitation steadily increases, reaching the annual maximum during March (fig. 2). While the amount of precipitation fluctuates in all zones, the variation is greater in the higher zones. The piñon-juniper zone receives 4.1 percent of its annual total during June and 11.5 percent during March, while in the spruce-fir zone the corresponding proportions are 2.6 percent during June and 15.5 percent during March.

Although seasonal and monthly precipitation data show definite seasonal trends, they are more accurately indicated by 5-day precipitation totals. Such data for the aspen-fir zone for the period May 1 to November 1 indicate continuous heavy precipitation until June 1, with an average of 0.55 inch during the May 26 to May 31 period. Thereafter a decrease takes place. The driest period of the year occurs from June 21 to June 25, when the average precipitation is 0.07 inch. A secondary maximum occurs during the period from July 26 to July 31, when the average is 0.50 inch. Following this period precipitation declines to a secondary minimum of 0.09 inch, which is reached from September 16 to September 20. As winter approaches, the amount of precipitation increases markedly. These precipitation trends hold true in all zones although the amounts differ (table 2).

Individual storms which occur during the summer months throughout the plateau area are usually moderate in the amount of moisture they deposit. The average precipitation per rainy day for the four zones is piñon-juniper, 0.12 inch; oakbrush, 0.21 inch; aspen-fir, 0.20 inch; spruce-fir, 0.20 inch. These totals vary, being greater during May and October in the higher zones and less during the intervening months in the lower zones (table 3).

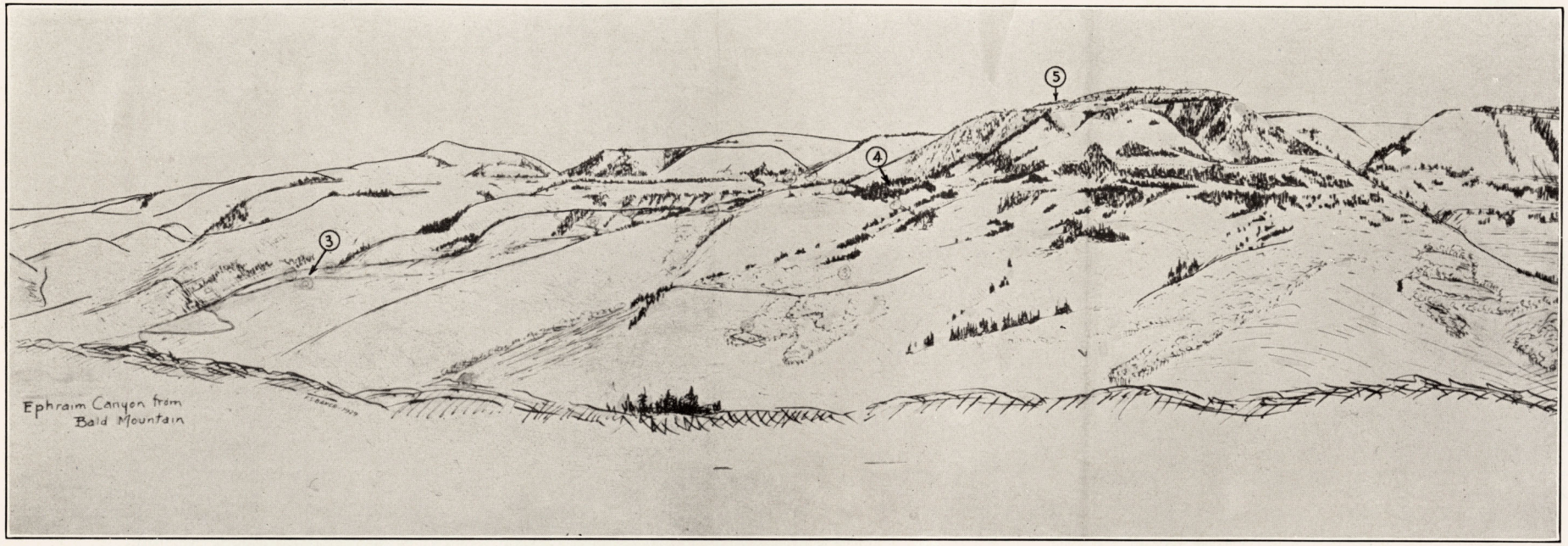

FIGURE 1.—Sketch showing a portion of the west front of the Wasatch Plateau in central Utah, prepared by F. S. Baker, Assoc. Prof. of Forestry, University of California. Circled numbers mark the location of the three upper meteorological stations. (3) = Oakbrush zone meteorological station, elevation 7,655 feet; (4) = Aspen-fir zone meteorological station, elevation 8,850 feet; (5) = Spruce-fir zone meteorological station, elevation 10,100 feet (the spruce-fir zone is located near the main summit in the background which can be seen in the distance).

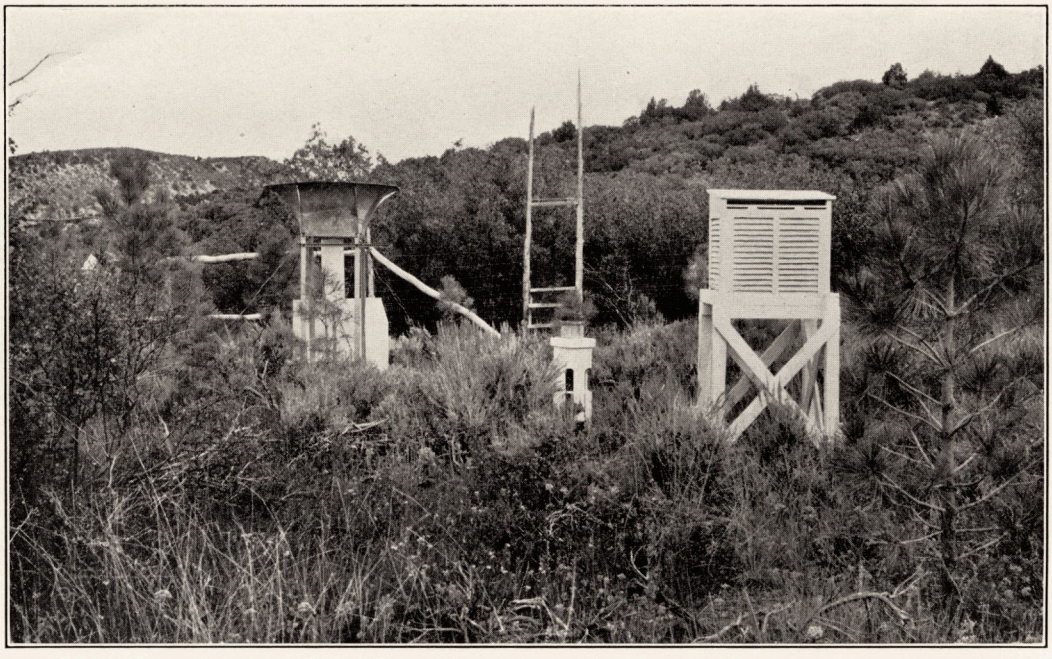

FIGURE 7.—Meteorological station in oakbrush zone in Ephraim Canyon, Utah.

FIGURE 8.—Meteorological station in spruce-fir zone near summit of Wasatch Plateau in Ephraim Canyon, Utah.

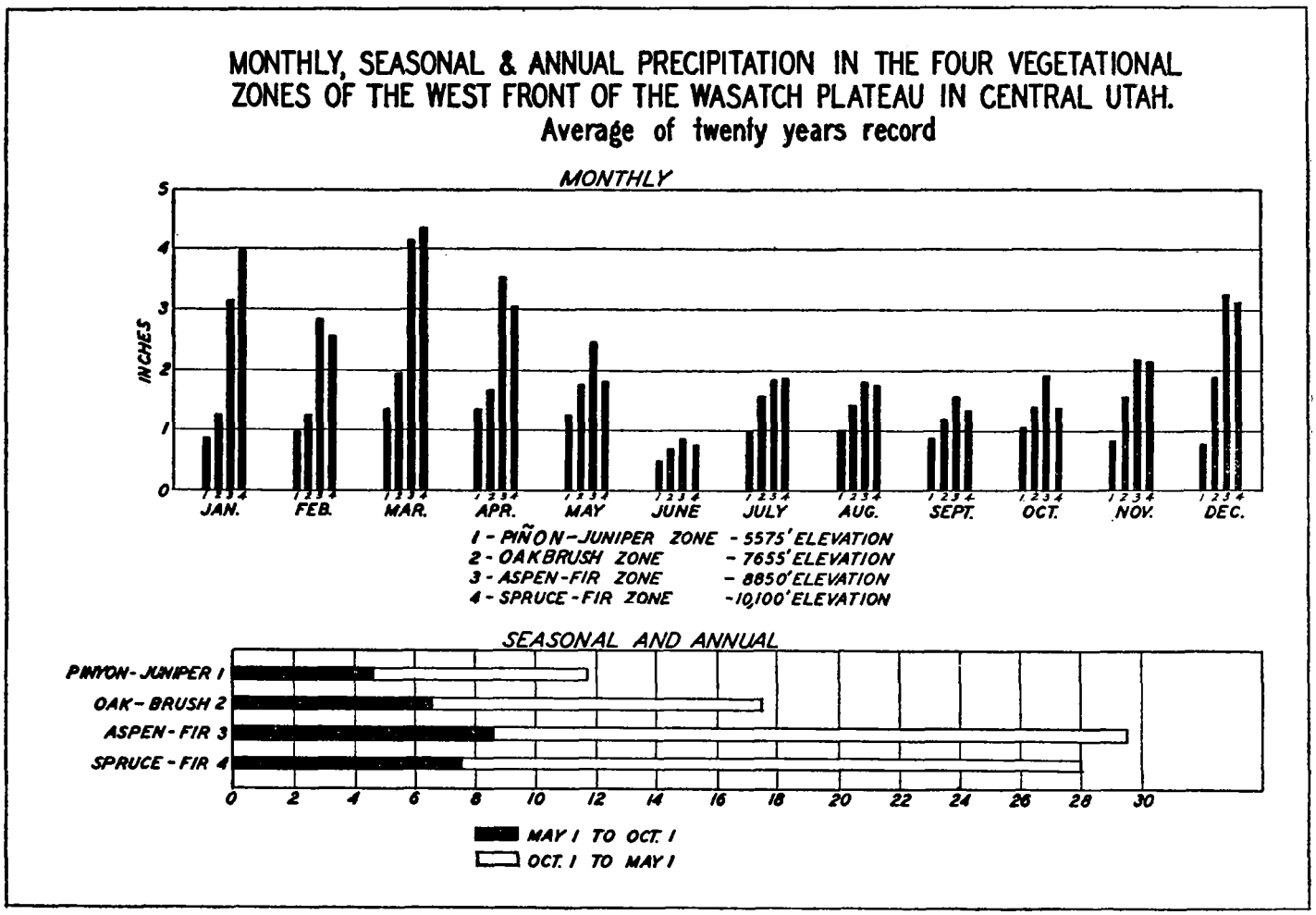

FIGURE 2.

TABLE 2.—*Summer precipitation by 5-day periods in four vegetational zones of the west front of the Wasatch Plateau in central Utah*

[Mean of 11 to 20 years' record]

PIÑON-JUNIPER ZONE (ELEVATION 5,575 FEET)

Period	May	June	July	August	September	October
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1-5	0.15	0.14	0.11	0.20	0.16	0.34
6-10	.28	.09	.16	.13	.17	.17
11-15	.14	.07	.18	.18	.15	.17
16-20	.27	.07	.10	.12	.04	.08
21-25	.17	.04	.22	.11	.28	.08
26-31	.25	.08	.20	.23	.09	.21

OAKBRUSH ZONE (ELEVATION 7,655 FEET)

1-5	0.19	0.13	0.12	0.33	0.26	0.27
6-10	.42	.08	.19	.25	.31	.27
11-15	.33	.10	.29	.22	.11	.19
16-20	.25	.10	.06	.14	.07	.16
21-25	.18	.07	.24	.15	.31	.13
26-31	.41	.14	.43	.35	.17	.39

ASPEN-FIR ZONE (ELEVATION 8,850 FEET)

1-5	0.30	0.22	0.22	0.38	0.26	0.45
6-10	.55	.12	.31	.35	.32	.34
11-15	.30	.11	.30	.30	.20	.23
16-20	.41	.18	.21	.18	.09	.18
21-25	.26	.07	.26	.21	.42	.18
26-31	.55	.15	.50	.37	.27	.54

TABLE 2.—*Summer precipitation by 5-day periods in four vegetational zones of the west front of the Wasatch Plateau in central Utah*—Con.

[Mean of 11 to 20 years' record]

SPRUCE-FIR ZONE (ELEVATION 10,100 FEET)

1-5	0.22	0.14	0.21	0.34	0.27	0.31
6-10	.32	.09	.24	.40	.27	.22
11-15	.49	.08	.34	.29	.19	.24
16-20	.28	.13	.25	.20	.09	.16
21-25	.28	.08	.39	.15	.35	.17
26-31	.45	.15	.44	.33	.17	.33

TABLE 3.—*Average precipitation during a rainy day in the vegetational zones of the west front of the Wasatch Plateau in central Utah*

[Rain or melted snow]

Zone	May 1-Nov. 1	May	June	July	August	September	October
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Pinon-juniper (elevation 5,575 feet)	0.12	0.15	0.07	0.09	0.10	0.12	0.17
Oakbrush (elevation 7,655 feet)	.21	.23	.18	.19	.18	.23	.24
Aspen-fir (elevation 8,850 feet)	.20	.24	.14	.15	.17	.21	.27
Spruce-fir (elevation 10,100 feet)	.20	.26	.18	.17	.16	.19	.26

Average number of rainy days.—Precipitation occurs during the months from May to October, inclusive, on an average of 46 days in the piñon-juniper, 39 days in the oakbrush, 54 days in the aspen-fir, and 45 days in the spruce-fir zones. Precipitation to the amount of 0.25 inch or more fell on each of the following number of days in the four zones: Piñon-juniper, 7; oakbrush, 12; aspen-fir, 14; spruce-fir, 11. Days that received 0.50 inch or more in the four zones follow: Piñon-juniper, 2; oakbrush, 4; aspen-fir, 6; spruce-fir, 4 (table 4). In the aspen-fir zone there have been as few as 37 rainy days (1917) and as many as 69 (1915) of the possible 184 during the 6-month period (May 1 to Nov. 1). The greatest number of rainy days per month usually occurs during July and August, and the least number in June. The greatest number on record is 20, which occurred in the aspen-fir zone during May 1915 and in July 1918 (table 5). The least number of rainy days is 1, which has occurred in all zones during June.

TABLE 4.—*Number of days, per month, with precipitation*

[Average of 10 to 20 years' record]

Number of days with precipitation of—	Total May 1–Nov. 1	May	June	July	August	September	October
PIÑON-JUNIPER ZONE (ELEVATION, 5,575 FEET)							
Trace or more	46	9	5	10	10	6	6
0.05 inch or more	24	5	2	4	5	4	4
0.25 inch or more	7	2	1	1	1	1	1
0.50 inch or more	2	(1)	0	(1)	0	(1)	1
OAKBRUSH ZONE (ELEVATION, 7,655 FEET)							
Trace or more	39	8	4	8	8	5	6
0.05 inch or more	29	7	2	5	6	4	5
0.25 inch or more	12	3	1	2	2	2	2
0.50 inch or more	4	1	0	0	1	1	1
ASPEN-FIR ZONE (ELEVATION, 8,850 FEET)							
Trace or more	54	10	6	12	11	8	7
0.05 inch or more	34	6	3	8	7	5	5
0.25 inch or more	14	4	1	2	2	2	3
0.50 inch or more	6	2	(1)	1	1	1	1
SPRUCE-FIR ZONE (ELEVATION, 10,100 FEET)							
Trace or more	45	7	4	11	11	7	5
0.05 inch or more	31	5	2	8	7	5	4
0.25 inch or more	11	2	1	2	2	2	2
0.50 inch or more	4	1	(1)	1	1	(1)	1

[1] Less than 0.5 inch day.

TABLE 5.—*Number of das tion which precipitation occurred in aspen-fir zone*

Year	Total, May–October	May	June	July	August	September	October
1914				14	6	4	8
1915	69	20	8	8	12	15	6
1916	47	4	1	15	12	5	10
1917	37	10	3	9	8	5	2
1918	68	14	8	20	6	8	12
1919	58	14	2	11	10	12	9
1920	57	4	9	8	14	10	12
1921			6	12	19	2	5
1922			7	8	13	3	6
1923	48	4	5	15	8	7	9
1924	41	6	3	10	8	6	8
1925	68	10	14	16	10	9	9
1926	51	13	7	13	9	5	4
1927	63	5	10	13	11	18	6
1928	47	19	5	3	7	2	11
1929	56	6	3	18	13	9	7
1930	66	10	6	13	17	12	8
1931	47	8	11	6	11	7	4
1932	46	9	6	12	13	4	2
1933	51	14	3	17	7	7	3
1934	39	4	8	7	9	6	5
Average	54.1	10.0	6.1	12.0	10.7	7.5	7.0

Drought periods.—The average number of rainless days between occurrences of storms of different amounts for the plateau area indicates approximately 10 days between occurrences of 0.05 inch or more precipitation in a day. This figure varies slightly for each zone, being 12.0 days for the piñon-juniper, 8.9 days for the oakbrush, 7.6 days for the aspen-fir, and 8.5 days for the spruce-fir zones. Individual drought periods during some years, however, continue throughout much of the summer. In the aspen-fir zone, for instance, 54 days elapsed without an occurrence of 0.05 inch of rain in a day during 1922; while in May and June 1933 a rainless period of 40 days was experienced. The number of days between occurrences of 0.50 inch or more of precipitation in one day for each of the four zones is: Piñon-juniper, 109.1 days; oakbrush, 59.6 days; aspen-fir, 33.8 days; spruce-fir, 40.2 days. Departures from these averages are considerable. During 1931 in the aspen-fir zone a period of more than 158 days elapsed between occurrences of 0.50 inch or more of precipitation. The opposite extremes are recorded for summers such as 1915, 1920, and 1930, when days with 0.50 inch or more of precipitation occurred on an average every 20 days (tables 6 and 7).

TABLE 6.—*Number of days between occurrences of precipitation of 0.05 inch or more and 0.50 inch or more in 1 day*

[10–20 years' record]

Station	Elevation	0.05 inch or more	0.50 inch or more
		May 1–Nov. 1	May 1–Nov. 1
	Feet		
Piñon-juniper	5,575	12.0	109.1
Oakbrush	7,655	8.9	59.6
Aspen-fir	8,850	7.6	33.8
Spruce-fir	10,100	8.5	40.2

TABLE 7.—*Average number of days between occurrences of precipitation in aspen-fir zone*

Year	0.50 inch or more in 1 day	0.05 inch or more in 1 day [1]					
	May 1–Nov. 1	May 1–Nov. 1	May	June	July	Aug.	Sept.	Oct.
1914					3	13	10	13
1915	20.1	8.7	2	14	18	18	8	20
1916	39.0	7.1	30	22	5	5	10	4
1917	23.6	7.6	3	10	12	7	10	43
1918	37.5	6.7	22	5	7	12	4	4
1919	26.1	7.8	17	42	11	6	6	7
1920	19.5	7.2	11	16	8	7	6	7
1921				13	5	3	17	17
1922				27	7	4	28	54
1923	33.2	7.3	8	12	5	6	8	8
1924	24.3	7.1	9	18	12	8	6	5
1925	25.3	5.7	7	7	5	4	6	8
1926	45.2	7.1	5	10	9	7	7	9
1927	35.4	7.7	10	10	7	9	4	25
1928	45.2	9.2	5	22	24	14	12	5
1929	35.0	5.4	12	16	4	4	6	7
1930	19.2	8.0	7	11	8	6	9	13
1931	91.5	10.7	10	19	18	9	5	14
1932	25.6	7.0	6	22	8	5	14	14
1933	29.5	8.7	11	40	8	7	12	20
Average	33.8	7.6	10	18	9	8	9	15

[1] Dry periods extend into other months until precipitation occurs.

Character of precipitation.—The higher the altitude the longer the snowfall period, and consequently the greater the proportion of the annual precipitation occurring as snow. Snowfall constitutes 45 percent of the total annual precipitation in the piñon-juniper, 60 percent in the oakbrush, 70 percent in the aspen-fir, and 80 percent in the spruce-fir zones.

The beginning and ending of the snowfall season is not abrupt but is characterized by storms of both rain and snow. The transition from rainfall to snowfall within the three upper zones occurs during September and October in the fall and from snowfall to rainfall during April, May, and June in the spring. The transition periods in the piñon-juniper zone are March and April in the spring and October and November in the fall. Snow has occurred during all months within all zones but only rarely during July and August. During October 13.5 percent of the total number of storms are snowstorms in the piñon-juniper, 34 percent in the oakbrush, 56 percent in the aspen-fir, and 66 percent in the spruce-fir zones. During May the percentages for the same zones are 2.9, 14, 45, and 84 percent, respectively.

A snow cover is usually present in the three upper zones by November 1. The average maximum depth is reached about March 1 in the oakbrush zone and approximately April 1 in the aspen-fir and spruce-fir zones. On these dates the average depths are 24.9 inches in the oakbrush, 48.5 in the aspen-fir, and 58.5 in the spruce-fir zones (table 8), although depths as great as 39 inches in the first-named zone, 65 in the second, and 84 in the third have been observed.

TABLE 8.—*Depth of snow and water content (in inches); average of 7 to 20 years' record for depth and 4 to 17 years for water content*

Zone	Nov. 1		Dec. 1		Jan. 1		Feb. 1		Mar. 1		Apr. 1		May 1	
	Depth	Water Content	Depth	Water Content	Depth	Water Content	Depth	Water Content	Depth	Water Content	Depth	Water Content	Depth	Water Content
Piñon-juniper	0.1	----	0.8	----	2.2	----	4.1	----	1.5	----	0.8	----	0	----
Oakbrush	3.3	----	6.5	1.53	15.2	3.02	22.3	4.59	24.9	5.89	17.8	5.55	----	----
Aspen-fir	5.0	----	13.9	2.93	27.7	5.51	38.9	8.00	47.3	10.18	48.5	14.56	25.5	8.34
Spruce-fir	5.8	----	19.1	----	31.5	7.37	41.2	10.19	52.9	14.71	58.5	17.28	----	----

Water content of the snow cover, in relation to the depth, increases with the advance of the snowfall season. At the beginning the ratio is 1:5 which increases to 1:3 during April and May when melting occurs in the spring. Water content of the snow cover, in relation to annual precipitation, is 34 percent on March 1 in the oakbrush zone, 49 percent in the aspen-fir, and 62 percent in the spruce-fir zones on April 1.

The date of snow disappearance is delayed on an average of approximately 15.5 days per 1,000 feet rise in altitude. Snow is off, on the average, by April 18 in the oakbrush zone, May 6 in the aspen-fir zone, and May 26 in the spruce-fir zone.

Trend of precipitation.—Considerable periodic variation in annual precipitation is evidenced by the following data taken from records in the piñon-juniper zone at Manti, Utah, during the past 34 years:

1901–04 ..... 9.69 inches, 83 percent of normal
1905–09 ..... 17.06 inches, 146 percent of normal
1910–22 ..... 12.95 inches, 111 percent of normal
1923–30 ..... 11.28 inches, 96 percent of normal
1930–34 ..... 7.88 inches, 67 percent of normal

During the 12 years 1923 to 1934, only 2 years (1927 and 1930) received above normal precipitation. However, during 4 of the 12 years (1923, 1925, 1927, 1930) summer rainfall was above normal (figure 3).

Temperature.[3]—Temperatures vary greatly between vegetational zones. Annual mean temperatures are 46.9° in the piñon-juniper, 42.6° in the oakbrush, 38.0° in the aspen-fir, and 32.5° in the spruce-fir zones (figure 4). On an average, temperatures decrease 3.2° per thousand feet rise in altitude or approximately 4.8° between zones. Departures from these rates are considerable, depending on the time of day and the season of the year. During the day the rate of variation increases to an average of 4.7° per thousand feet rise at the time of maximum temperatures and decreases to an average of 1.7° per thousand feet rise at the time of minimum temperature. The gradient is greatest during spring when a snow cover is present at the high altitudes but absent in the valley, and least during winter when there is a snow cover on all zones. Maximum gradients for the year occur in April, averaging 4.6° per thousand feet rise and minimum gradients occur in January averaging 1.6° per thousand feet rise (table 9).

TABLE 9.—*Average decrease in temperature per thousand-foot increase in elevation (degrees F.)*

	Annual	January	February	March	April	May	June	July	August	September	October	November	December
In maxima	4.7	3.1	3.6	5.9	6.3	5.6	5.0	4.6	4.6	4.6	4.8	4.4	4.0
In minima	1.7	.0	1.4	2.9	3.0	2.5	1.7	1.6	1.5	1.5	1.5	1.3	1.6
In mean	3.2	1.6	2.5	4.4	4.6	4.0	3.4	3.1	3.0	3.0	3.2	2.8	2.8

Seasonal fluctuations from the annual mean temperatures are considerable, being greatest in the valley and decreasing toward the summit. The mean temperatures for the winter season (October 1 to May 1) are 35.6° in the piñon-juniper, 31.6° in the oakbrush, 27.3° in the aspen-fir, and 21.7° in the spruce-fir zones. The mean temperatures for the summer season May 1 to October 1 for the same zones are: 62.6°, 57.9°, 53.0°, and 47.6° respectively (table 10).

Monthly mean temperatures in the piñon-juniper zone range from 69.5° in July to 23.8° in January, making an annual range of 45.7°. In the spruce-fir zone the means are 55.3° in July and 16.8° in January making an average annual range of 38.5°. Similar fluctuations occur in the intervening zones. The coldest month of record is January in the two lower zones and December in the two higher zones. July is the hottest month of the year in all zones (figure 4).

TABLE 10.—*Mean seasonal temperatures (percent of annual)*

Zone	Elevation	May 1–Oct. 1	Oct. 1–May 1
	Feet	*Percent*	*Percent*
Piñon-juniper	5,575	62.6	35.6
Oakbrush	7,655	57.9	31.6
Aspen-fir	8,850	53.0	27.3
Spruce-fir	10,100	47.6	21.7

Daily fluctuations in temperature are greatest on the valley floor at the base of the plateau and decrease with increase in elevation. The average daily range in temperature is 28.4° in the piñon-juniper zone and 14.7° in the spruce-fir zone. This variation is due to the uniformity of minimum temperatures and the wide spread of maximum temperatures. Annual mean minimum temperatures range less than 8° between the lowest and highest zones, while the annual mean maximum temperatures range more than 21°.

[3] All temperatures Fahrenheit.

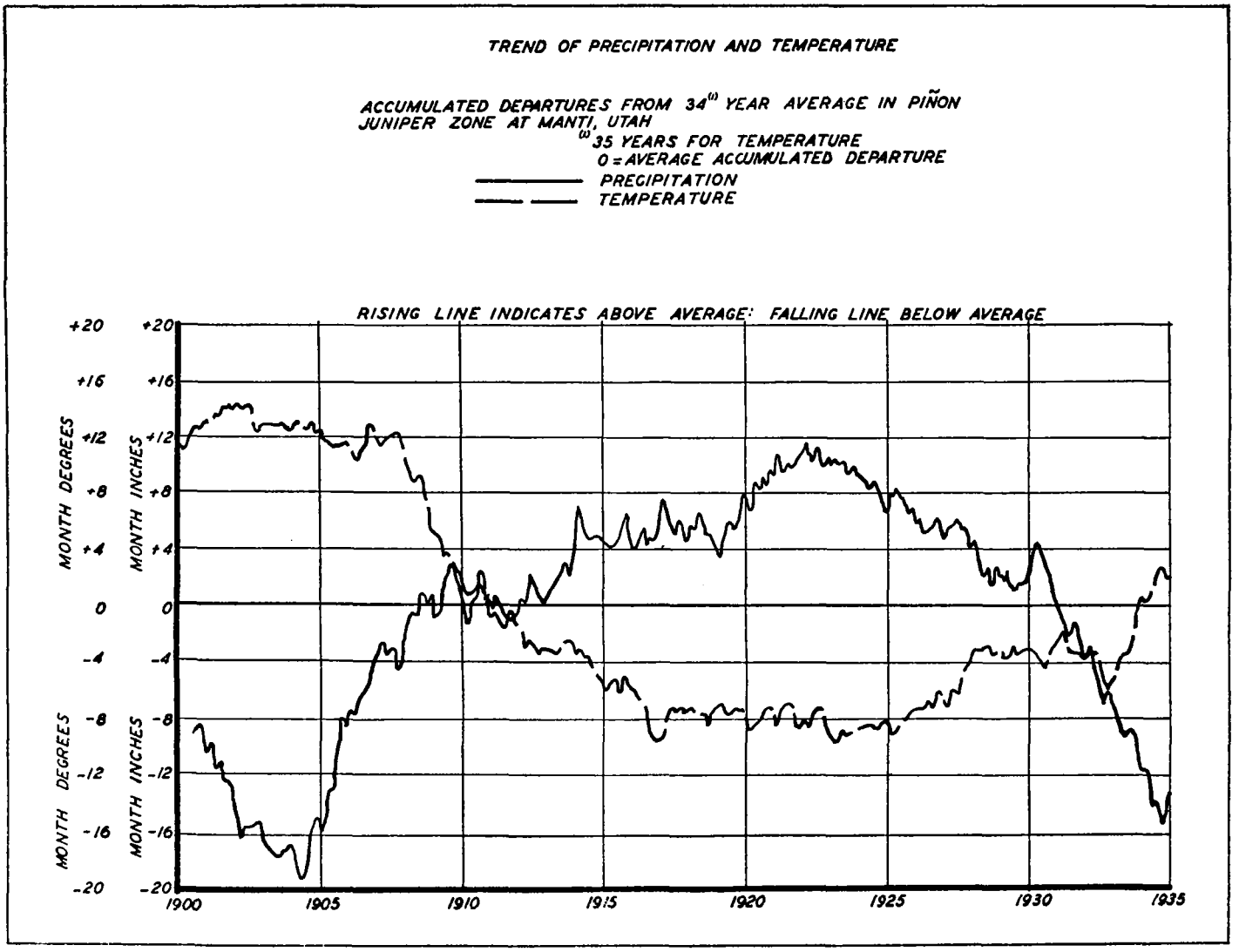

FIGURE 3.

Records for 5-day periods show that temperatures in all zones increase steadily throughout the early spring and summer, reaching the seasonal maximum during the period July 16 to 20; thereafter, temperatures decline throughout the remainder of the summer (table 11).

Extremes in temperature.—Highest temperatures of record range from 82° in the spruce-fir zone to 101° in the piñon-juniper zone. The absolute maximum temperature for the oakbrush zone is 97° and for the aspen-fir zone 88°. Temperatures above 90° are unknown in the aspen-fir and spruce-fir zones but they have occurred during June, July, and August in the oakbrush and piñon-juniper zones. Below-zero temperatures have been recorded during 6 months in the piñon-juniper zone, 7 months in the oakbrush and aspen-fir zones and 8 months in the spruce-fir zones (table 12).

TABLE 11.—*5-day mean temperature normals*

Zone	Elevation	Period	May	June	July	Aug.	Sept.	Oct.
	Feet		°F.	°F.	°F.	°F.	°F.	°F.
Piñon-juniper	5,575	1-5	51	57	68	68	63	53
		6-10	50	61	69	67	62	53
		11-15	53	63	70	68	60	49
		16-20	57	63	71	67	60	49
		21-25	56	67	70	67	57	48
		26-31	56	68	70	65	55	44
Oakbrush	7,655	1-5	43	53	64	65	60	49
		6-10	42	56	64	64	53	47
		11-15	46	59	66	64	56	43
		16-20	50	58	67	64	56	42
		21-25	49	63	67	64	51	41
		26-31	49	63	66	62	51	38
Aspen-fir	8,850	1-5	39	48	59	59	55	43
		6-10	40	51	60	59	53	41
		11-15	43	53	61	58	52	40
		16-20	44	55	61	58	49	38
		21-25	45	57	61	58	48	36
		26-31	46	59	60	56	45	36
Spruce-fir	10,100	1-5	32	42	54	54	50	39
		6-10	33	45	55	54	48	37
		11-15	35	47	56	54	47	35
		16-20	37	50	56	54	45	34
		21-25	38	52	56	53	43	32
		26-31	39	54	55	52	40	32

TABLE 12.—*Extreme annual and monthly temperatures from 20-year record*[1]

	Annual	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Maxima	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Piñon-juniper, elevation 5,575 feet	101	63	24	77	80	87	96	101	99	90	82	73	59
Oakbrush, elevation 7,655 feet	97	63	59	64	74	83	97	96	91	87	80	71	66
Aspen-fir, elevation 8,850 feet	88	58	56	56	70	73	86	88	84	77	70	59	60
Spruce-fir, elevation 10,100 feet	82	49	53	43	52	66	77	82	76	71	67	55	48
Minima													
Piñon-juniper, elevation 5,575 feet	−26	−22	−26	0	12	18	27	32	34	25	11	−8	−21
Oakbrush, elevation 7,655 feet	−30	−24	−30	−11	−4	11	17	23	23	14	5	−14	−24
Aspen-fir, elevation 8,850 feet	−30	−20	−30	−14	−7	4	19	23	26	11	2	−13	−20
Spruce-fir, elevation 10,100 feet	−21	−21	−20	−12	−5	5	14	29	20	11	−1	−16	−14

[1] Winter extremes in upper zones for fewer number of years.

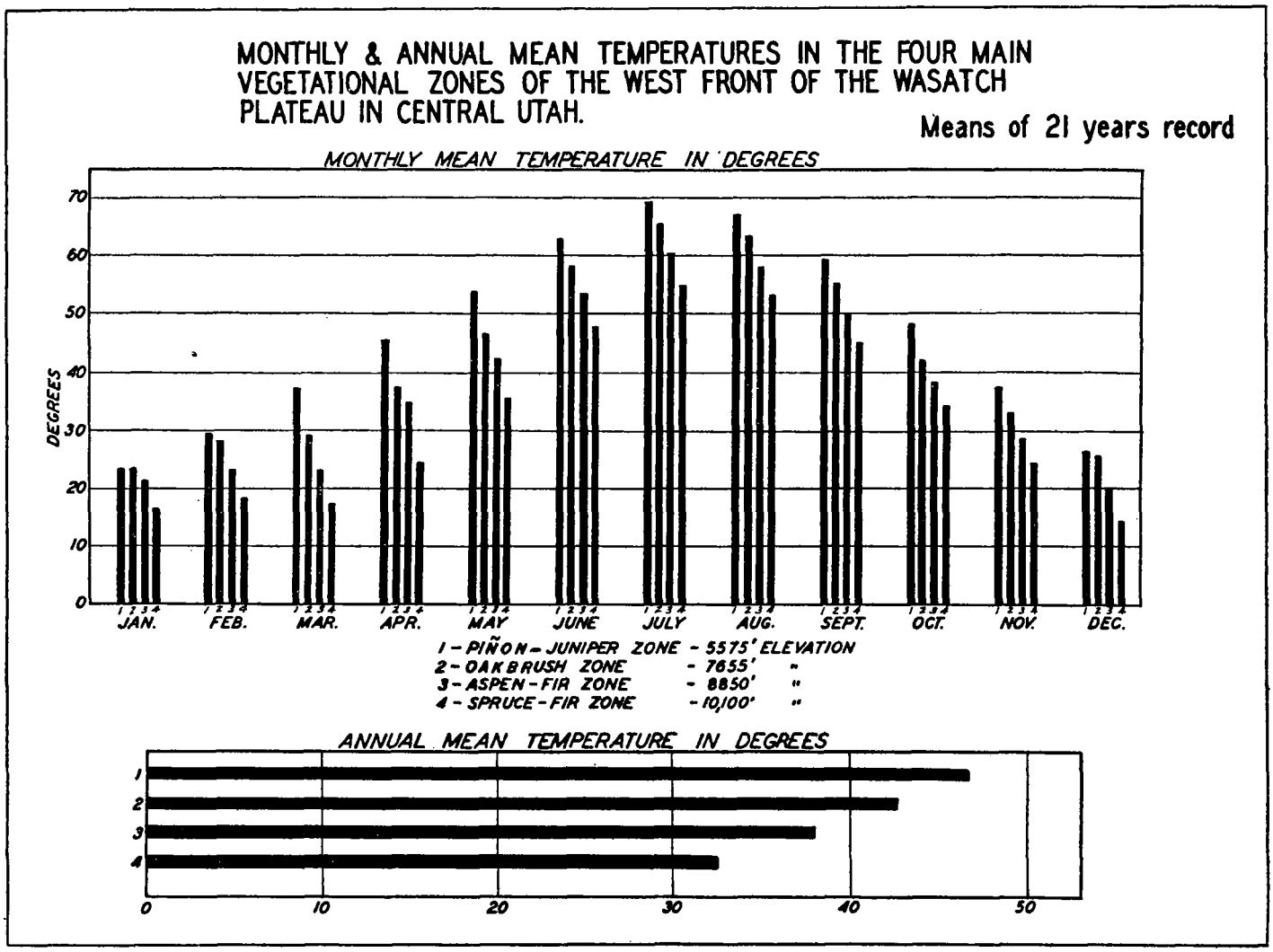

FIGURE 4.

Length of frost-free periods.—Average lengths of the frost-free period (when temperatures are above 32°) in the three upper zones are nearly uniform, being 90 days for the oakbrush, 87 days for the aspen-fir, and 80 days for the spruce-fir zones. Departures from these averages are considerable, the frost-free season having been as short as 53 days and as long as 122 days in the oakbrush zone, during the period of record. The average dates of the last temperatures of 32° occurring in the spring are May 28 for piñon-juniper, June 17 for oakbrush and aspen-fir, and June 18 for spruce-fir zones. The first temperature of 32° occurring in the fall for the same zones are: Sept. 25, Sept. 15, Sept. 12, and Sept. 6, respectively. The latest date on record of a temperature of 32° or lower in the spring is July 12, which occurred in the spruce-fir zone, and the earliest temperature of 32° or lower in the fall is August 16, which occurred in the spruce-fir zone (table 13).

Considerable variation exists between zones in the length of the period when minimum temperatures average above 32°. Such periods are 146 days in the oakbrush, 140 days in aspen-fir, and 110 days in the spruce-fir zones. Although this period is shortest in the spruce-fir zone, it is less disrupted by occasional frosts at the beginning and ending of the season (table 14).

TABLE 13.—*Dates of last temperature of 32° F. in spring, first in fall, and length of frost-free period (1913–33 record)*

	Date of last 32° temperature in spring				Date of first 32° temperature in fall				Length of frost-free period			
	Piñon-juniper	Oak-brush	Aspen-fir	Spruce-fir	Piñon-juniper	Oak-brush	Aspen-fir	Spruce-fir	Piñon-juniper	Oak-brush	Aspen-fir	Spruce-fir
Earliest	Apr. 29	May 30	May 30	June 1	Sept. 10	Aug. 27	Aug. 20	Aug. 16				
Latest	July 3	July 9	July 7	July 12	Oct. 19	Oct. 6	Oct. 5	Sept. 22				
Average	May 28	June 17	June 17	June 28	Sept. 25	Sept. 15	Sept. 12	Sept. 6	120	90	87	80
Longest									147	122	114	111
Shortest									79	53	61	54

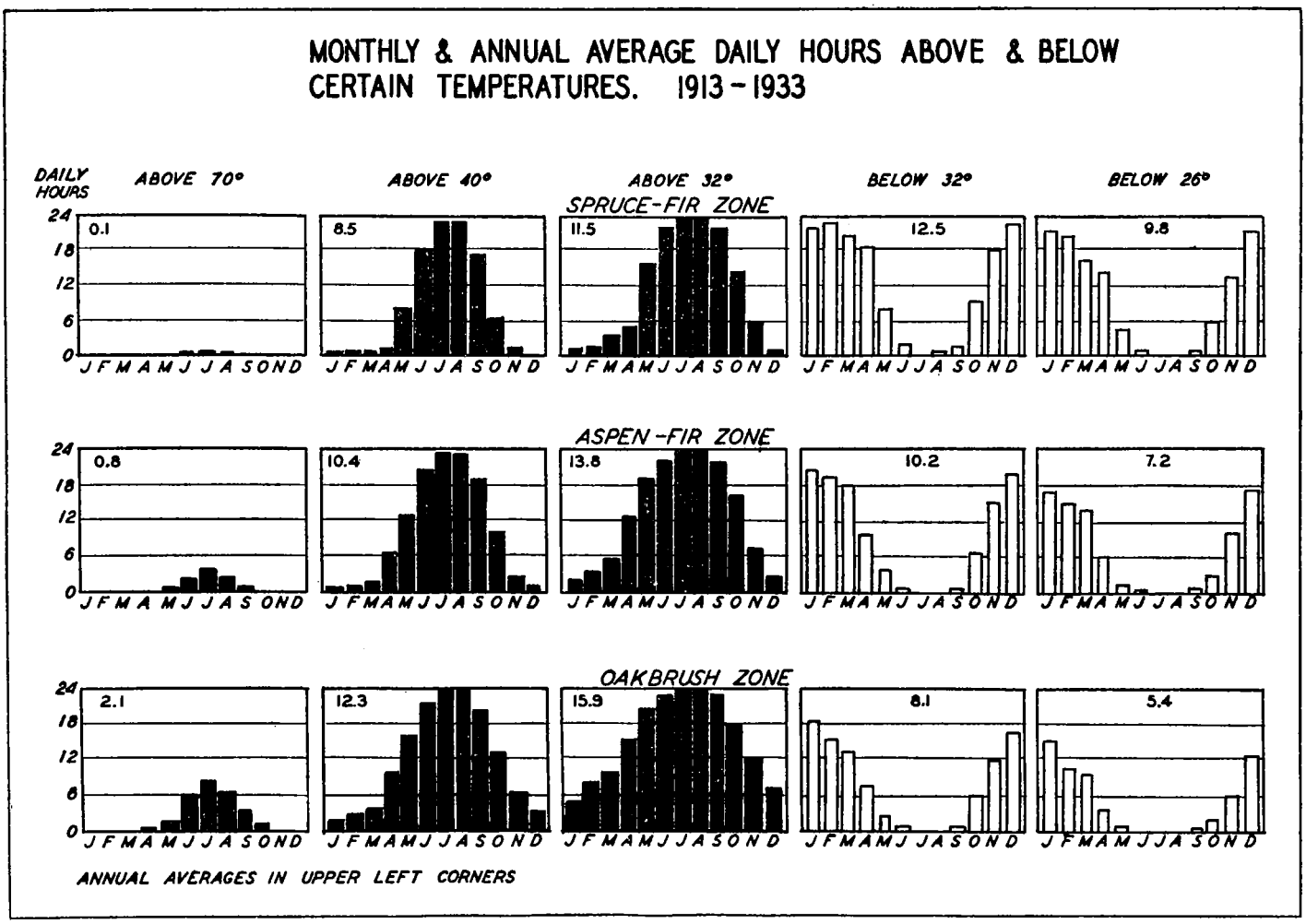

FIGURE 5.

TABLE 14.—*Beginning, ending, and length of period when minimum temperatures average above 32° F. (average of 1913–33 record)*

	Piñon-juniper	Oak-brush	Aspen-fir	Spruce-fir
Date when minimum temperatures average above 32° in spring	----------	May 15	May 16	June 9
Date when minimum temperatures average below 32° in fall	----------	Oct. 8	Oct. 3	Sept. 27
Length of period (number of days) when minimum temperatures average above 32°	----------	146	140	110

Number of hours above and below certain temperatures.—The average number of daily hours with temperatures above 32°, above 40°, and above 70°, are greater in the oakbrush zone and decrease proportionally in the aspen-fir and spruce-fir zones. Conversely, the number of daily hours below 26° and below 32° is greater in the spruce-fir zone and decreases in the two lower zones. The average number of daily hours above 32°, on an annual basis, are 15.9 for the oakbrush, 13.8 for the aspen-fir, and 11.5 for the spruce-fir zones, while the number of hours below 32° are 8.1, 10.2, and 12.5, respectively, for the same zones (figure 5).

Trend of temperature.—As shown by a 34-year temperature record in the piñon-juniper zone, above-normal temperatures generally accompany below-normal precipitation; and below-normal temperatures are associated with above-normal precipitation (figure 3). During the period 1901 to 1904 precipitation was below normal and temperatures were above. On the other hand, during the period 1905 to 1909 precipitation was above normal and temperatures were below. Similar variations occurred during the periods 1910 to 1922, 1923 to 1930, and 1930 to 1934.

OTHER FACTORS STUDIED

(Oakbrush, aspen-fir, and spruce-fir zones)

Soil temperature.—Soil temperatures at depths of 6, 12, and 24 inches fluctuate with air temperatures. During the winter snowfall period temperatures are nearly uniform at these three depths. After disappearance of snow in the spring, and during the summer, temperatures are highest at the shallower depths, while during the fall and winter the opposite holds true. Observations made during one winter, 1915–16, in the aspen-fir zone, indicated a tem-

perature of 32.0° F. at the 6-inch depth and slightly higher temperatures at the two lower depths throughout the period when a snow cover was present. With the disappearance of the snow cover in the spring (May 8), soil temperatures increased 10.4° at the 6-inch depth, 6.1° at the 12-inch depth, and 3.5° at the 24-inch depth in 5 days (figure 6).

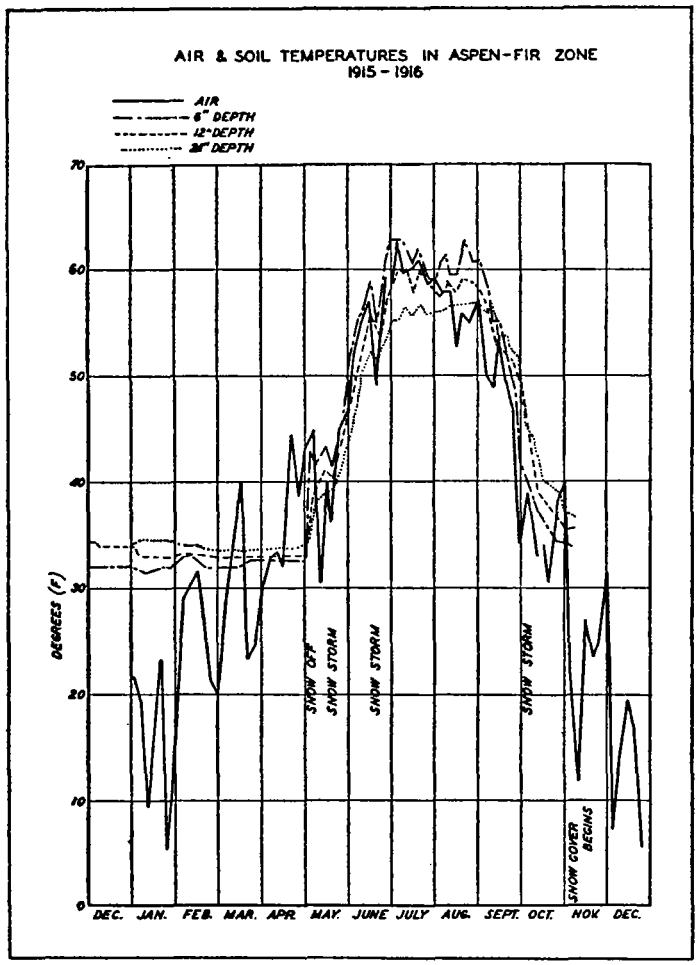

FIGURE 6.

Monthly means of soil temperatures in the aspen-fir zone for the May 1–November 1 period show that average temperatures are highest during July at the 6- and 12-inch depths and highest during August at the 24-inch depth. Average temperatures at the three depths rise steadily during May and June. Throughout August the temperatures average very close to the seasonal maximum and during September and October temperatures decline abruptly at all depths (table 15).

Records of soil temperatures at 5-day periods show that the greatest variation between depths occurs during the latter part of June at which time there is an average difference of 4.5° between the 6- and 12-inch depths and 5.2° between 12- and 24-inch depths. Temperatures average highest during the July 16 to 31 period at the 6- and 12-inch depths and from July 26 to August 5 at the 24-inch depth (table 16).

Hourly observations of soil temperatures (1913) indicate that on an average summer day there is a diurnal range of approximately 12° at the 6-inch depth, 3° at the 12-inch depth, and less than 1° at the 24-inch depth. Maximum temperatures at the 6-inch depth occurred from 6 p. m. to 7 p. m., or 4 to 5 hours after the peak of the air temperature was reached. At the 12- and 24-inch depths the maximum soil temperatures showed similar lags of approximately 10 hours and 24 hours, respectively.

Soil temperature data taken at infrequent intervals in the oakbrush and spruce-fir zones indicate similar trends. The data show that soil temperatures in the oakbrush zone vary from less than 1° higher to 2° higher than those in the aspen-fir zone, while at the spruce-fir zone they vary from 9° lower in the spring to 3° lower in the fall.

Soil moisture.—Soil moisture is not usually considered to be a climatic factor; but because it is largely determined by climatic factors, it is included in this study. Determinations were made on an oven dry-weight basis at depths of 6, 12, and 24 inches (18 inches at spruce-fir zone) similar to the method outlined by Weaver and Clements (8; *pp. 185–188*) and are expressed as percentages of dry weight of samples.

Soil moisture during the season from June 1 to November 1 averages from 15 to 17 percent in the oakbrush, 19 percent in the aspen-fir, and 20 percent in the spruce-fir zones. Percentages as low as 6 and as high as 51 have been recorded, but more ordinary extremes are 15 and 40 percent (table 17).

Variation in this factor between zones is greatest at the beginning of the season (May and June) when a snow cover is yet present at the spruce-fir zone, and gradually decreases throughout the summer period until the difference in October is 4 percent or less at all depths. The oakbrush zone has the least amount of soil moisture, ranging from 0 percent to 12 percent below amounts of the aspen-fir and spruce-fir zones which have similar percentages.

TABLE 15.—*Monthly means* [1] *of soil temperatures in the aspen-fir zone*

Period	May			June			July			August			September			October		
	6 inches	12 inches	24 inches	6 inches	12 ineches	24 inches	6 inches	12 inches	14 inches	6 inches/	12 inches	24 inches	6 inches	12 inches	24 inches	6 inches	12 inches	24 inches
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1924				59.1	55.2	49.9	64.0	61.5	56.8	63.9	61.4	57.5	54.6	54.7	54.1	39.9	41.6	44.2
1925	53.0	49.0	44.2	53.2	51.0	48.2	62.1	59.2	54.7	59.5	58.0	55.3	51.5	52.0	51.6	39.7	41.4	44.0
1926	49.1	46.3	42.9	61.0	57.4	52.4	62.8	59.6	55.2	64.1	61.4	57.4	55.1	54.9	54.2	43.2	44.6	46.2
1927				57.2	53.8	49.0	62.3	59.3		60.2	58.4		52.0	52.0		41.9	42.9	
1928	48.2	44.8		55.9	53.3	49.8	63.7	60.6	56.0	63.8	61.7	58.6	57.3	56.6	55.7	43.3	45.0	47.5
1929				55.1		46.7	61.2	58.4	54.5	59.3	57.4	54.7	50.5	50.1	50.2	43.8	44.6	46.2
1930				56.3	53.1	49.0	62.8	59.4	55.4	58.7	56.9	55.0	50.7	50.9	51.5	38.6	39.6	41.9
1931				59.7	54.7	50.2	68.0	62.8	57.5	64.8	61.5	58.1	55.7	55.3	54.6	44.0	45.3	46.7
1932	46.9	43.0	40.0	57.2	52.3	48.4	62.7	59.2	55.4	59.7	58.2	55.8	52.3	52.5	52.2	40.3	43.1	45.1
1933				59.6	53.2	47.2	64.5	60.7	56.3	62.2	59.5	56.8	56.7	55.6	54.2	44.8	46.2	47.4
1934	54.8	51.8	48.1	56.2	53.8	51.1	65.2	61.8	57.8	62.7	60.9	58.4	55.5	55.7	55.3	44.0	45.8	47.4
Average	50.4	47.0	43.8	57.3	53.8	49.3	63.6	60.2	56.0	61.7	59.6	56.8	53.8	53.7	53.4	42.1	43.6	45.7

[1] Average of 8 a. m. and 5 p. m. readings.

TABLE 16.—*Mean soil temperatures* [1] *at three depths by 5-day periods in aspen-fir zone (average of 3 to 11 years' record)*

Period	May			June			July			August			September			October		
	6 inches	12 inches	24 inches	6 inches	12 inches	24 inches	6 inches	12 inches	24 inches	6 inches	12 inches	24 inches	6 inches	12 inches	24 inches	6 inches	12 inches	24 inches
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1–5	42.9	41.2	39.1	52.0	49.3	45.0	62.8	59.1	54.4	62.8	60.5	57.1	58.8	57.3	55.8	45.9	47.0	48.7
6–10	46.2	43.2	41.3	53.6	50.6	46.3	62.3	59.1	55.0	61.5	59.5	56.6	56.8	56.1	55.1	45.1	46.0	47.6
11–15	48.4	44.8	41.6	56.8	52.9	48.5	63.1	59.6	55.3	61.7	59.4	56.6	54.6	54.2	53.8	42.3	44.1	46.3
16–20	50.5	46.6	43.1	57.9	54.6	50.0	64.9	61.2	56.2	62.2	59.8	56.8	54.6	54.1	53.4	41.0	42.7	44.8
21–25	51.1	48.0	44.5	61.3	56.8	51.6	64.2	61.1	56.8	62.4	59.8	56.8	50.8	51.7	52.2	39.3	41.3	43.4
26–31	50.8	49.3	45.0	62.1	58.2	53.3	64.1	61.3	57.3	60.1	58.7	56.6	47.5	48.8	50.0	38.2	40.3	42.6

[1] Average of 8 a. m. and 5 p. m. readings.

Soil-moisture percentages fluctuate more widely near the surface than at deeper levels due to weather changes. For instance, in May, June, and July 1933, during a 39-day drought, soil moisture decreased 22.0 percent within 6 inches of the surface, 11.6 percent in the 6-inch depth, and 10.9 percent in the 12-inch to 24-inch depth. A storm of 1.03 inches of rain followed this drought period and 3 days later, increases in soil moisture of 9.6 percent were indicated by the samples for the 0- to 6-inch depth; 3.0 percent for the 6- to 12-inch depth; and 0.7 percent for the 12- to 24-inch depth.

TABLE 17.—*Average soil-moisture percentages, means of 3 to 11 years' record, in percent of dry weight of soil*

Zone	Depth	June 1–Nov. 1	May	June	July	Aug.	Sept.	Oct.
	Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Oakbrush	0– 6	15	25	15	13	14	15	16
	6–12	16	27	21	16	16	16	15
	12–24	17	26	21	16	16	16	15
Aspen-fir	0– 6	19	28	22	19	19	21	20
	6–12	19	31	25	19	19	20	18
	12–24	19	31	26	20	19	19	16
Spruce-fir	0– 6	20	.....	27	21	21	21	16
	6–12	20	.....	28	22	20	21	16
	12–18	20	.....	28	22	20	19	16

Cloudiness (Piñon-juniper and aspen-fir zones).—Average daily cloudiness as indicated by eye observations for the piñon-juniper and aspen-fir zones is 5.7 and 5.4 tenths of the sky, respectively. Cloudiness is at a maximum in both zones during the winter and early spring and is least in late spring and fall.

Records of cloudiness for 5-day periods in the aspen-fir zone indicate considerable variation throughout the summer season (May 1–Nov. 1). Cloudiness varies from a maximum of 6.2 tenths in middle and late May to a minimum of 3.3 tenths in late June, and to 4.1 tenths during the latter part of October (tables 18 and 19).

TABLE 18.—*Average daily cloudiness in piñon-juniper and aspen-fir zones*

[Number of tenths of sky clouded; average of 4 to 20 years' record]

Zone	Annual	January	February	March	April	May	June	July	August	September	October	November	December
Piñon-juniper	5.7	5.8	6.0	6.0	6.2	6.2	5.3	5.7	6.1	5.4	5.2	5.4	5.5
Aspen-fir	5.4	7.0	6.0	4.4	6.1	6.1	4.5	5.2	5.1	4.6	4.8	6.5	5.0

TABLE 19.—*Summer cloudiness in aspen-fir zone*

[Number of tenths of sky clouded; average of 10 to 20 years' record]

Period	May	June	July	August	September	October	May–October
1–5	6.1	5.3	4.3	5.3	5.2	6.0	.....
6–10	6.1	4.9	5.3	5.2	4.7	5.3	.....
11–15	6.2	5.1	5.1	5.6	3.8	4.9	.....
16–20	5.7	4.7	5.3	4.9	4.4	4.4	.....
21–25	6.2	3.3	5.6	4.4	4.7	4.2	.....
26–31	6.1	4.0	5.6	4.9	4.6	4.1	.....
Average	6.1	4.5	5.2	5.1	4.6	4.8	5.1

Relative humidity (aspen-fir zone).—The seasonal relative humidity trend in the aspen-fir zone follows closely that of precipitation. In June, the driest month, the humidity averages 39.5 percent, while in May, the month of greatest precipitation for which humidity records are available, the average is 53.0 percent. The average during the May 1 to November 1 season is 48.2 percent (tables 20 and 21). However, extremes as low as 4 and as high as 100 percent have been recorded.

Average relative humidity in the aspen-fir zone varies from 53.6 percent at 8 a. m. to 42.8 percent at 5 p. m. during the May 1 to November 1 season. The difference between the two readings throughout the season averages approximately 10.8 percent with a maximum of 12.9 percent in May and a minimum of 8.8 percent in July.

TABLE 20.—*Relative humidity percentages in the aspen-fir zone*

[Average of 6 to 12 years' record; 100 percent equals saturation]

	May 1–Nov. 1	May	June	July	Aug.	Sept.	Oct.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
8 a. m.	53.6	59.4	44.6	53.4	54.7	53.7	56.1
5 p. m.	42.8	46.5	34.4	44.6	43.5	43.1	44.5
Mean	48.2	53.0	39.5	49.0	49.1	48.4	50.3

TABLE 21.—*5-day mean* [1] *percentages of relative humidity in the aspen-fir zone*

[Average of 3 to 12 years' record; 100 percent equals saturation]

Period	May	June	July	Aug.	Sept.	Oct.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1–5	63	43	43	53	49	52
6–10	61	39	47	50	48	49
11–15	58	41	48	48	45	54
16–20	60	39	48	49	44	53
21–25	46	36	49	46	49	45
26–31	44	37	55	49	55	44

[1] Average of 8 a. m. and 5 p. m. readings.

SUMMARY AND CONCLUSIONS

Climatic data presented in this study were collected during the 20-year period, 1914 to 1934, within the four main vegetational zones, designated as piñon-juniper, oakbrush, aspen-fir, and spruce-fir, ranging in elevation from 5,575 feet to 10,100 feet, on the west front of the Wasatch Plateau in central Utah. Observations were made with standard meteorological equipment by the Great Basin branch of the Intermountain Forest and Range Experiment Station, near Ephraim, Utah. The United States Weather Bureau cooperated in furnishing a number of the instruments used in the study.

Data summarized in this report include: Precipitation and atmospheric temperatures in the four vegetational zones; soil temperatures and amounts of soil moisture in the oakbrush, aspen-fir, and spruce-fir zones; extent of cloudiness in the piñon-juniper and aspen-fir zones; and relative humidity determinations in the aspen-fir zone.

As shown by these data, precipitation and atmospheric temperatures of the area vary widely between vegetational zones, owing to differences of elevation and topography. Total annual precipitation varies from 11.70 inches in the piñon-juniper zone on the valley floor, to 29.48 inches in the aspen-fir zone near the middle of the plateau front, and 28.01 inches in the spruce-fir zone at the summit. Of these totals, 45 percent, 70 percent, and 80 percent, respectively, is received during the winter season, November 1 to May 1, in the form of snow. The remainder falls in the form of moderate rains distributed throughout the summer season, May 1 to November 1. Summer thunderstorms are interspersed with rainless periods which occur during the main growing season and have extended for 158 days, and longer, between occurrences of 0.50 inch or more precipitation.

The month of June, a critical period for plant growth, receives the least precipitation in all zones. A secondary rainy season occurs during July and part of August, followed by an extreme dry period that extends into October.

The trend of precipitation for the 34-year period, 1901 to 1934, inclusive, at the piñon-juniper zone shows considerable periodic variation characterized by above- and below-normal precipitation. Consecutive years with below-normal precipitation have numbered as many as 12 during this time.

Temperatures as high as 101° F. have been recorded in the piñon-juniper zone and as low as −30° in the oakbrush and aspen-fir zones.

The growing season within the area is extremely short, the frost-free period being only 90 days in the oakbrush, 87 days in the aspen-fir, and 80 days in the spruce-fir zones.

In view of the limited amount and sporadic nature of precipitation and the extremes in atmospheric temperatures during the short growing season, plans for proper management of this area must recognize the delicate balance between this existing climate and the vegetational cover and provide for moderate grazing use and controlled timber-cutting practices.

Such a program will maintain an adequate plant cover which will guard against serious soil erosion and insure a permanent water supply sufficient to meet the needs of the adjacent communities. Also, records of the existing climate indicate that areas already depleted of plant cover can be rehabilitated only by controlled grazing use and by planting forage species especially adapted to withstand the drought periods and extreme fluctuations in temperature characteristic of this area.

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THE GEOMETRICAL THEORY OF HALOS—V

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IMAGES PRODUCED BY SIMPLE REFLECTION

Superimposing figure 7 on the celestial sphere, we have figure 17 and formulae D for the calculation of an image produced by simple reflection from an arbitrarily oriented plane with normal inclined at any angle ψ' to the vertical.

When the reflecting plane is vertical, $\psi'=90°$ and

$$\begin{aligned} D&=180°-2i,\\ \cos A'&=\tan\frac{D}{2}\tan H, \qquad (D^*)\\ H'&=H,\\ \sin\frac{\zeta}{2}&=\sin\frac{D}{2}\sec H, \end{aligned}$$

as may be found either directly from formulae D or by constructing the corresponding special case of figure 17. The rotation of a vertical plane about a vertical axis will therefore distribute the reflected light in a right cone with vertical axis and with one of its generators parallel to the incident ray; the locus of the images formed by this conical dispersion is a small circle parallel to the horizon.

When the reflecting plane is horizontal $\psi'=0°$, $i=90°-H$; and either from formulae D or directly from figure 7,

$$\begin{aligned} D&=2H,\\ A'&=180°, \qquad (D^{**})\\ H'&=-H,\\ \zeta&=0°. \end{aligned}$$

The rotation of a horizontal plane about a vertical axis will not disperse the reflected light at all, but will merely form a vertical image as far below the horizon as the source is above.